GIS-based Land Suitability Analysis for Identifying Solar Development Potential in the State of Illinois

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Overview

- Scope of the Project
- MCDA (Multi-Criteria Decision Analysis) and AHP (Analytic Hierarchy Process) Methodologies
- Results of Solar Development Suitability and Scenario Comparison
- Case Application for the Allerton Park

Scope of the Project

Objectives

1. To evaluate the appropriateness and feasibility for solar development in Illinois
2. To spatially identify the suitability using the MCDA method
3. To provide a practical site-specific suggestion

MCDA and AHP Methodologies

Multi-Criteria Decision Analysis

Multi-Criteria Decision Analysis (MCDA) using the Geographic Information System (GIS) is a widely used method to determine the best sites, solve the conflicts of location suitability, and harmonize the tradeoffs and risks.

In the coupling of GIS and MCDA, the suitability is quantified spatially based on a set of geographical criteria. Spatial vector data, (e.g., road networks) are converted into a raster format in GIS with specific manners, such as Euclidian distance or Kernel density, which make each cell contain a numeric value that can be calculated with others. A set of vector data (rasterized) and raster data with equal-size grids comprise the criteria of MCDA. In this study, the suitability is computed through weighted overlay procedures that each cell (30m × 30m) value of a criterion dataset is summed with corresponding cell values of other criteria being weighted with particular coefficients. Herein, the values of every criterion are rescaled (ranked) accordingly beforehand to enable computation within the same unit.

$$S_k = \sum_{j=1} C_{jk} W_j \, E_k$$

where S_k is the suitability of cell k, C_{jk} is a ranked value of cell k in criterion j, W_j is the assigned weight of criterion j, and E_k is a binary value of whether cell k is located within the constraint areas (1 = non-constraint area, 0 = constraint area).

Criteria Selection

Based on the previous studies concerning solar development, we structured a set of evaluation criteria to compute the degree of suitability in consideration of the three sustainability elements:
(1) environment, (2) socials and (3) economics in Illinois

Selected Criteria

Category	Criteria	Data sources
Environmental criteria	Solar radiation (C1)	[43]
	Slope degree (C2)	
	Slope aspect (C3)	
	Elevation (C4)	
Social criteria	Land uses (C5)	[40]
	Impervious surface percentage (C6)	
Economic criteria	Accessibility to road networks (C7)	[44]
	Distance to transmission lines (C8)	
	Crop productivity (C9)	[42]

Exclusion Criteria (Constraint area)

- Water bodies
- 100-year floodplain
- Illinois Protected areas

Combined Suitability Scores

Ranks (reclassification) of Evaluation Criteria

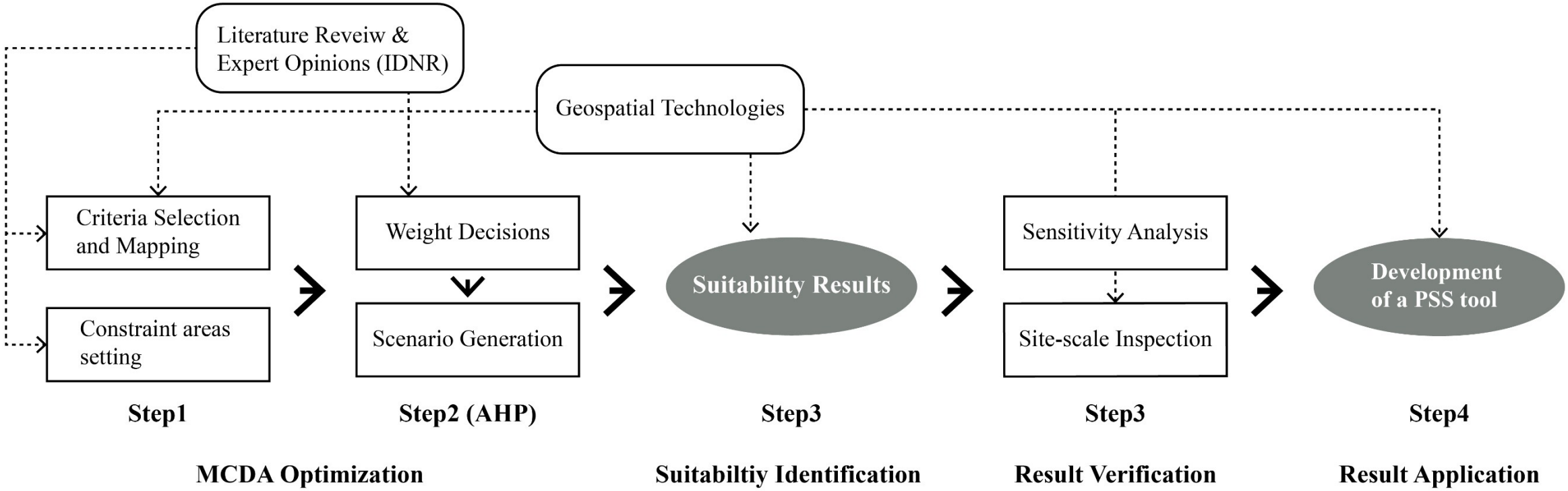
Criteria	Rank*				
	1	2	3	4	5
Solar radiation ($kWhm^{-2}yr^{-1}$)	<1200	1200-1300	1300-1400	1400-1500	>1500
Slope Percentage (%)	>10	5-10	3-5	1-3	<1
Aspect	N	NE, NW	FLAT, E, W	SW, SE	S
Elevation (m)	<400	400-600	600-800	800-1000	>1000
Land use and land cover	Wetlands/waters, and Forest	Urban areas	Herbaceous, and Agricultural uses	Shrubland, and Open space	Barren land
Population center density			Quantile method		
Accessibility to road networks			Quantile method		
Distance from transmission line (m)	>20000	10000-20000	1600-4800	800-1600	<800
Crop productivity*			Quantile method		

*Higher rank indicates higher suitability. Each criterion exhibits rough assessment of potential for solar development.

*The National Commodity Crop Productivity Index (NCCPI) by USDA

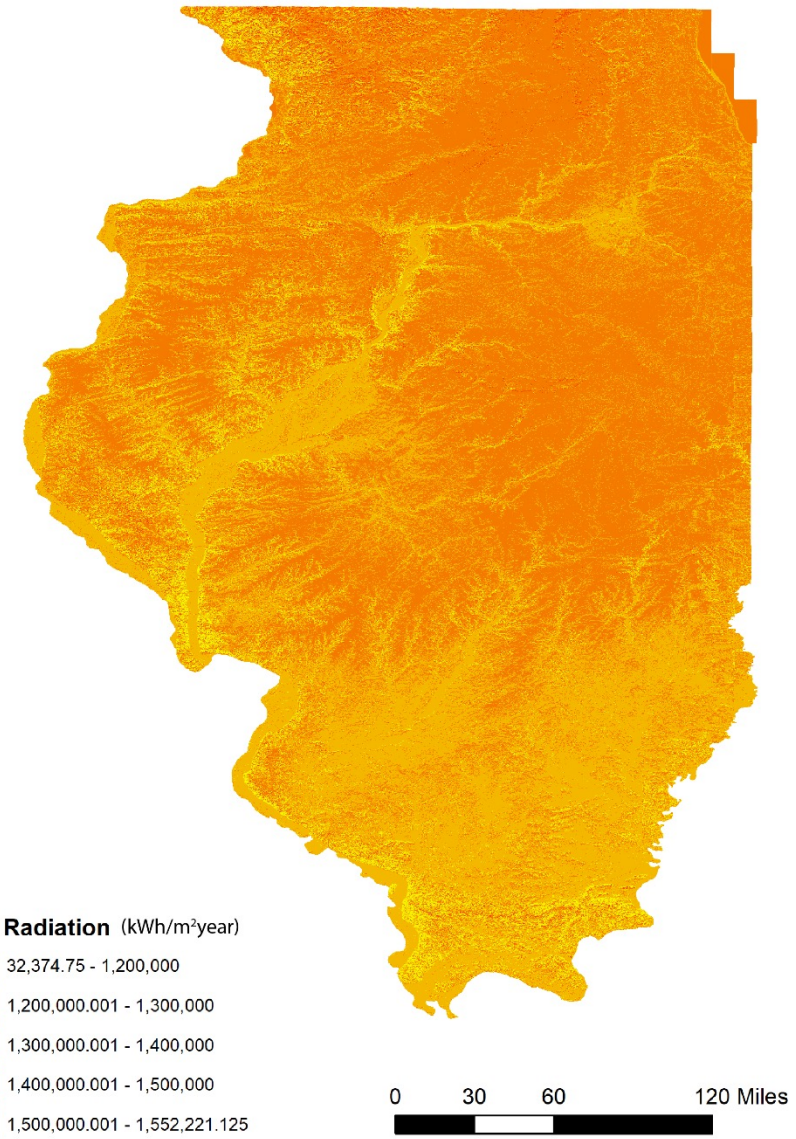
*The Kernel Density method was used for calculating Population center density and Accessibility for road networks.

Process of the Research

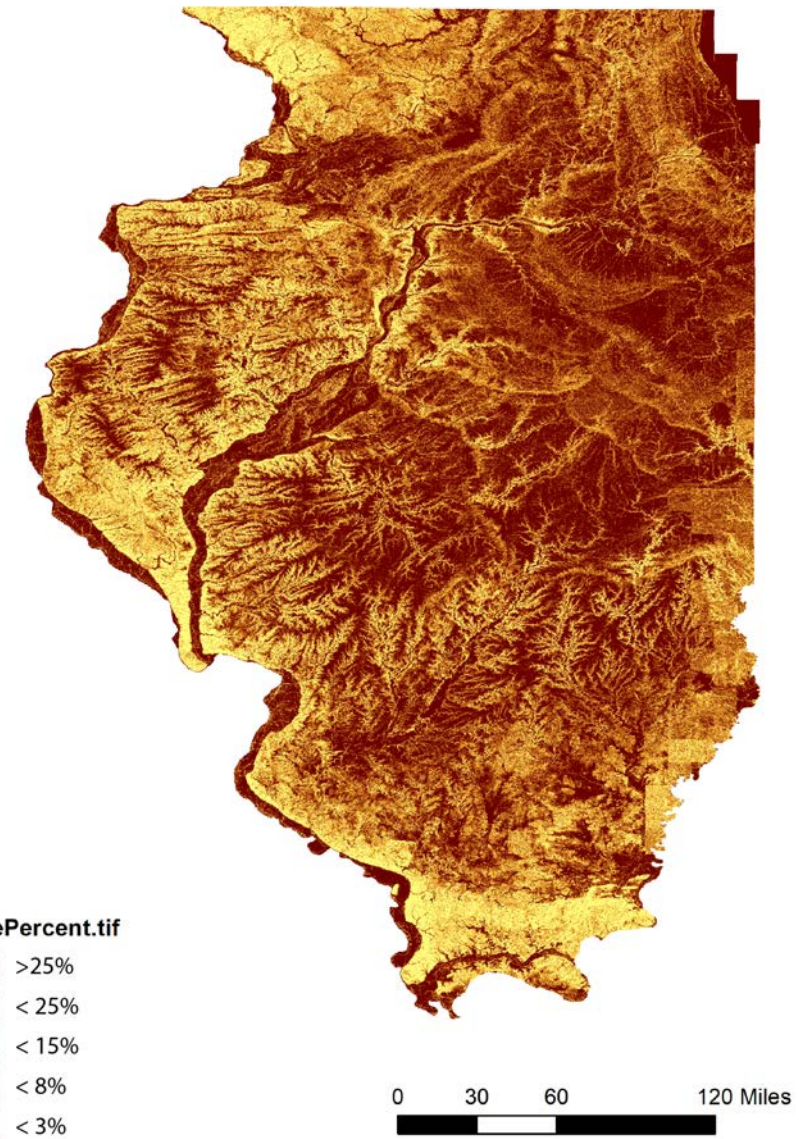


Environmental Criteria

C1: Solar Radiation



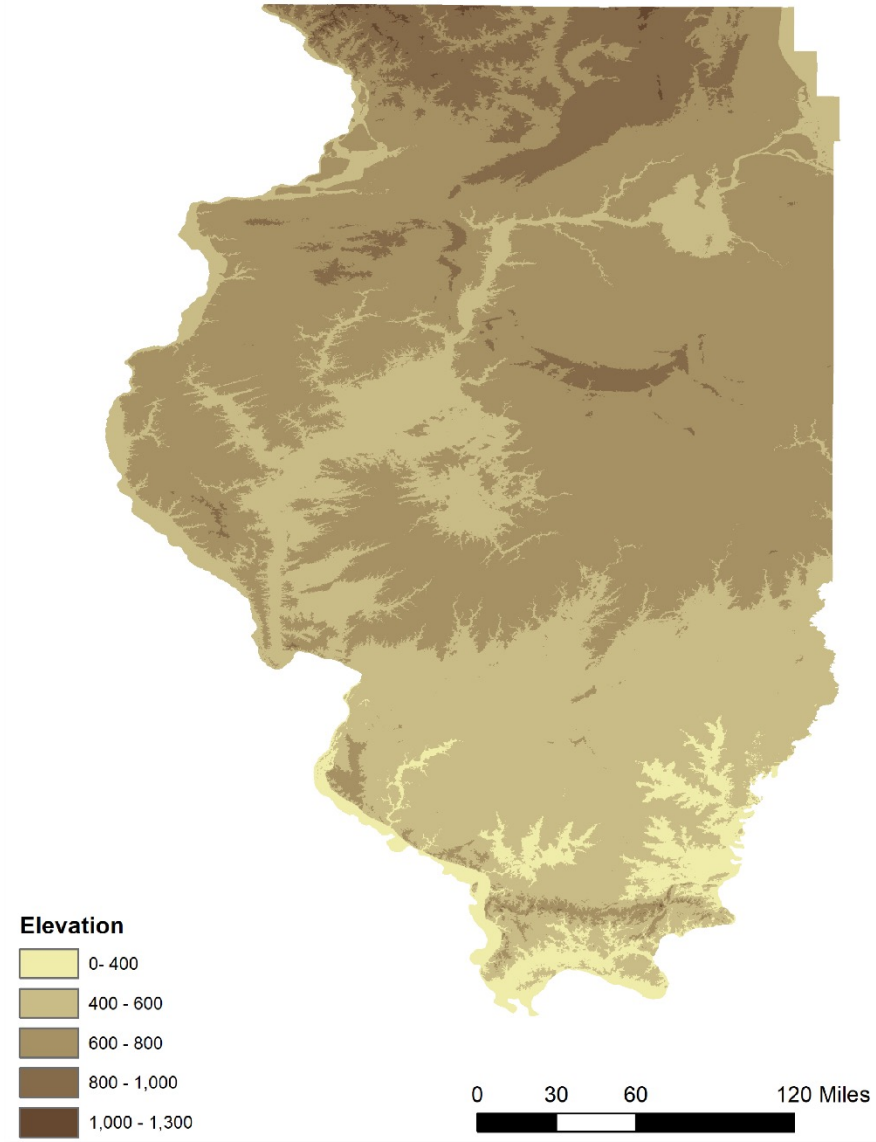
C2: Slope Percentage



Environmental Criteria

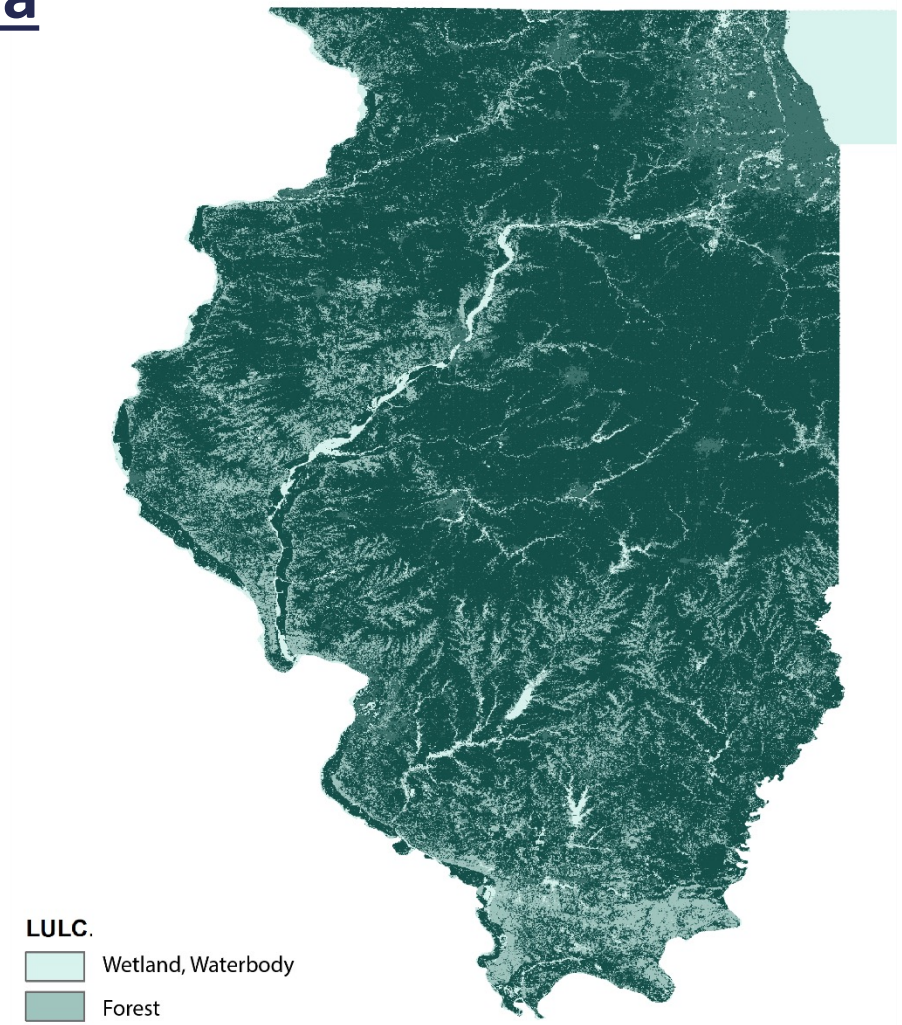
C3: Aspect

C4: Elevation



Social Criteria

C5: Land-uses



Less Suitable

↓

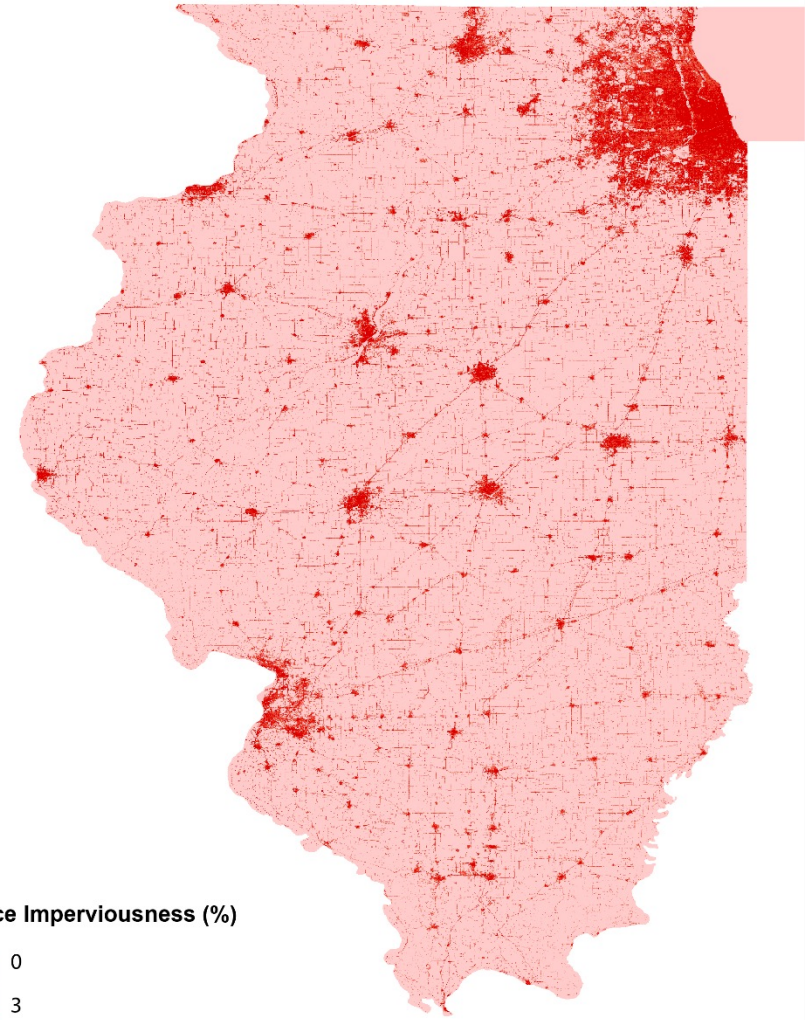
More Suitable

LULC.

- Wetland, Waterbody
- Forest
- Shrub, Grass land
- Developed land
- Barren Land, Open Space, Pasture...

0 30 60 120 Miles

C6: Impervious Surface Ratio



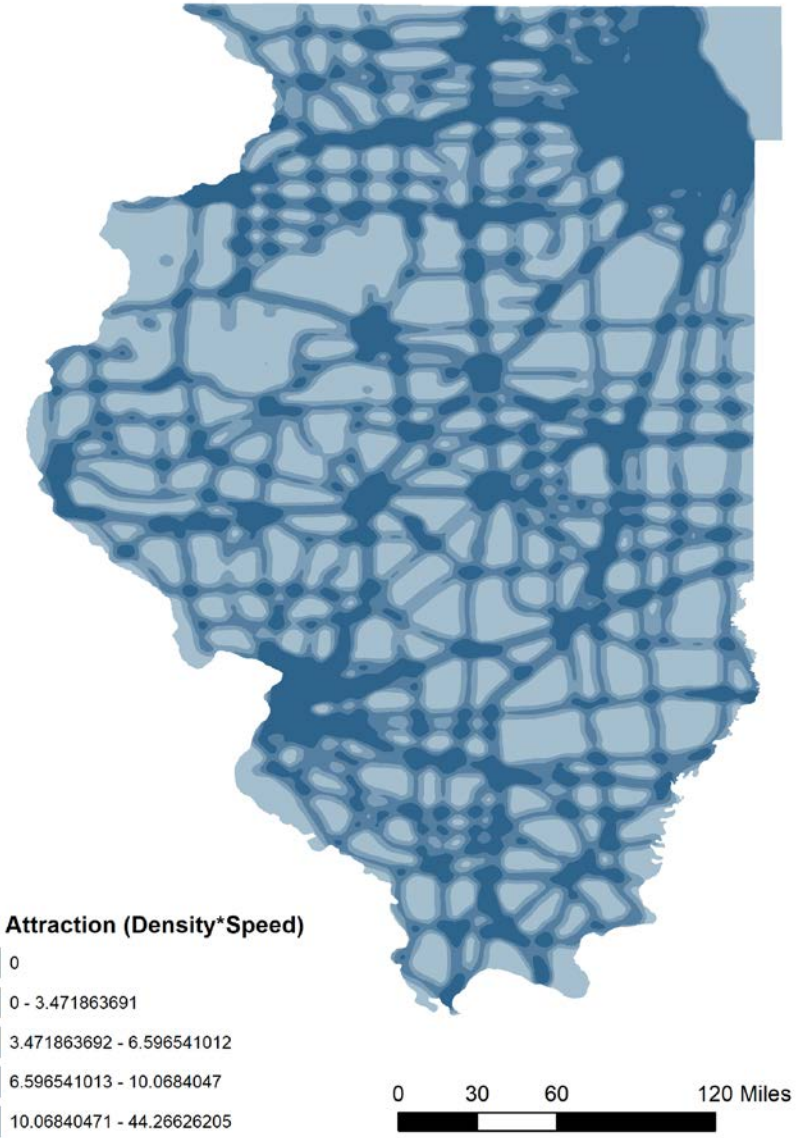
Surface Imperviousness (%)

- 0
- 3
- 12
- 35
- 100

0 30 60 120 Miles

Economic Criteria

C7: Road Attraction

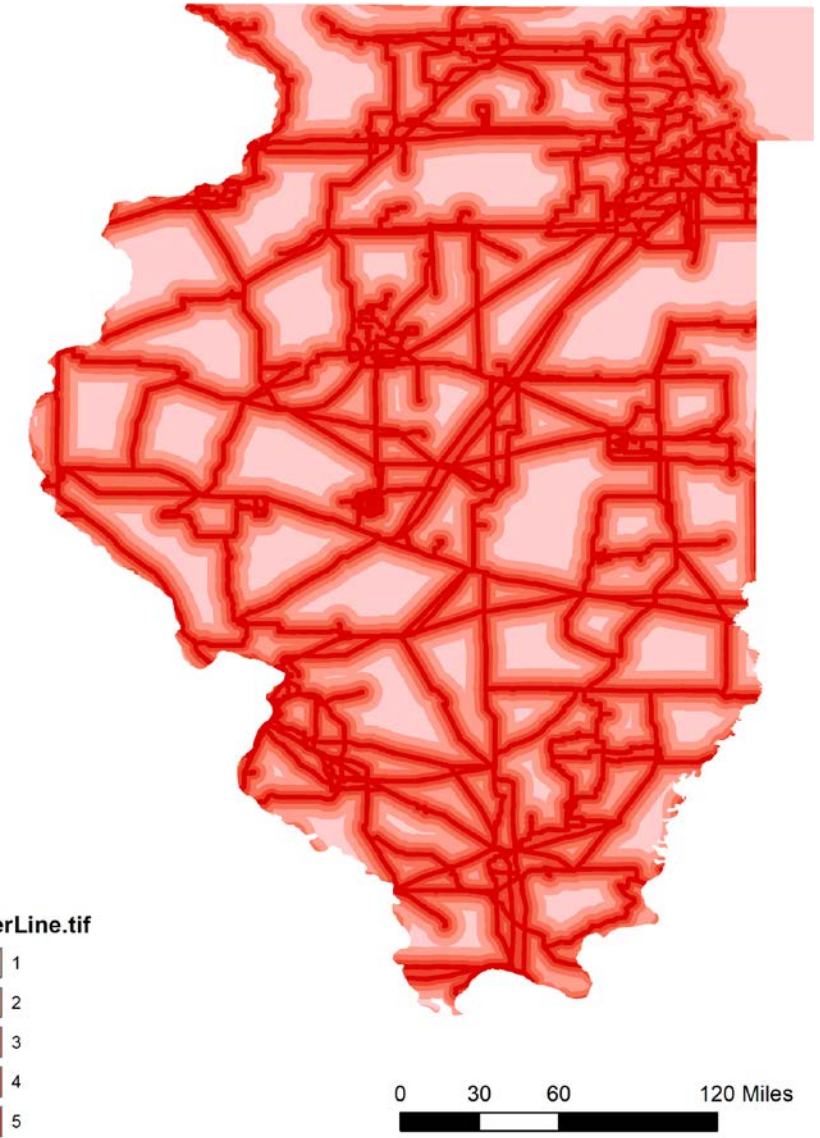


Less Suitable

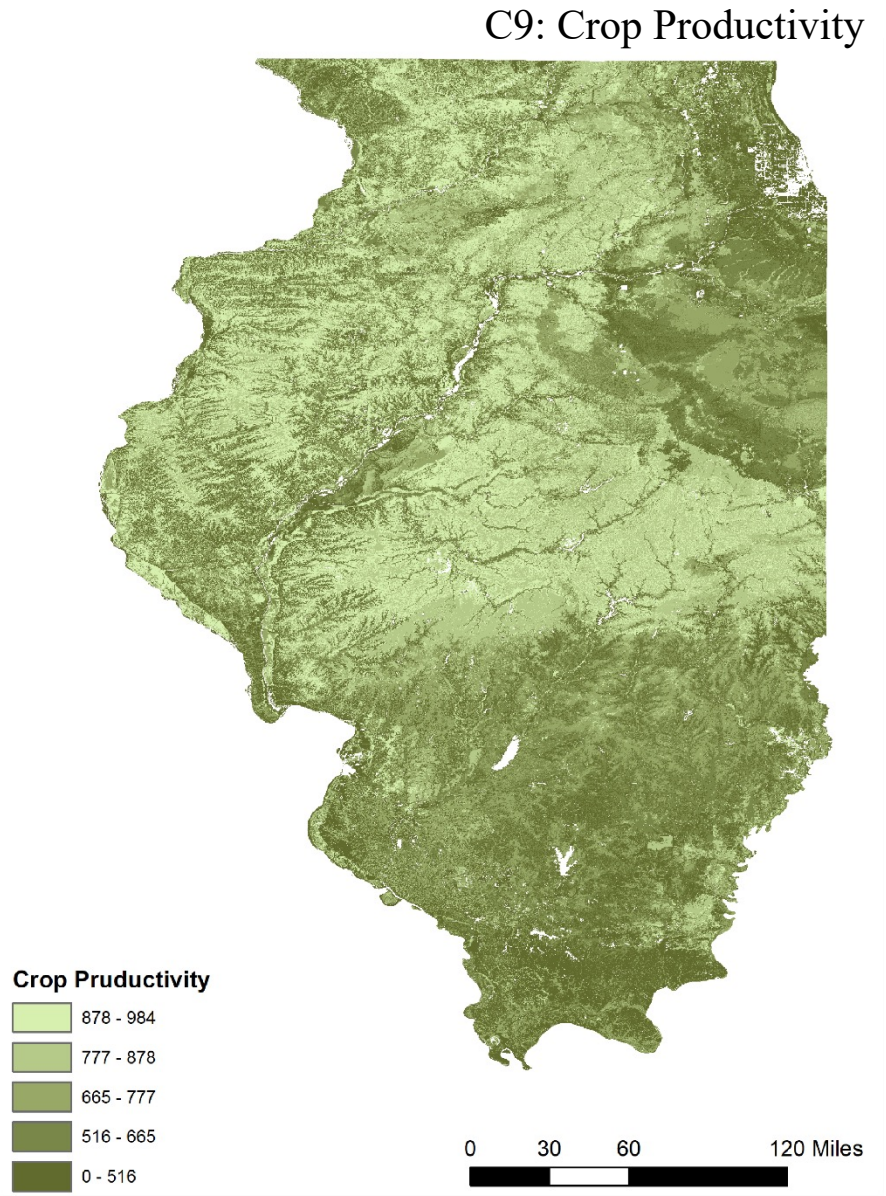
↓

More Suitable

C8: Distance to Power lines



Economic Criteria



This map displays the National Commodity Crop Productivity Index derived from the SSURGO soil database.

Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a theory of measurement through pair wise comparison. The comparisons are made using a scale of absolute judgements that represents how much more; one element dominates another with respect to a given attribute. The derived priority scales are synthesized by multiplying them by the priority of their parent nodes and adding for all such nodes

AHP operates through pairwise comparison within a reciprocal matrix that uses a scale of absolute judgment that represents how much one criterion dominate another. The process involves two stages: 1) determination of the relative importance of each criterion, and 2) calculation of the relative weight.

Pairwise comparisons of the evaluation criteria.

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
Solar Rad. (C1)	1	5	8	7	5	9	7	5	9
Slope (C2)	1/5	1	5	3	3	7	5	1	7
Aspect (C3)	1/8	1/5	1	1	1/2	3	1	1/3	5
Elevation (C4)	1/7	1/3	1	1	1/2	3	1	1/3	5
LULC (C5)	1/5	1/3	2	2	1	5	3	1/2	7
Pop. Den. (C6)	1/9	1/7	1/3	1/3	1/5	1	1/3	1/5	3
Road Net. (C7)	1/7	1/5	1	1	1/3	3	1	1/3	4
Trans. Lines (C8)	1/5	1	3	3	2	5	3	1	8
Crop Prod. (C9)	1/9	1/7	1/5	1/5	1/7	1/3	1/4	1/8	1

*P_{ij} refers to the relative importance of criterion i over criterion j, and $P_{ij} \times P_{ji}$ should be equal to 1. For example, $P_{19} = 9$ signifies that solar radiation is judged to be extremely more important than crop productivity in determining the suitability of solar development.

Weights of the evaluation criteria under the scenarios generated.

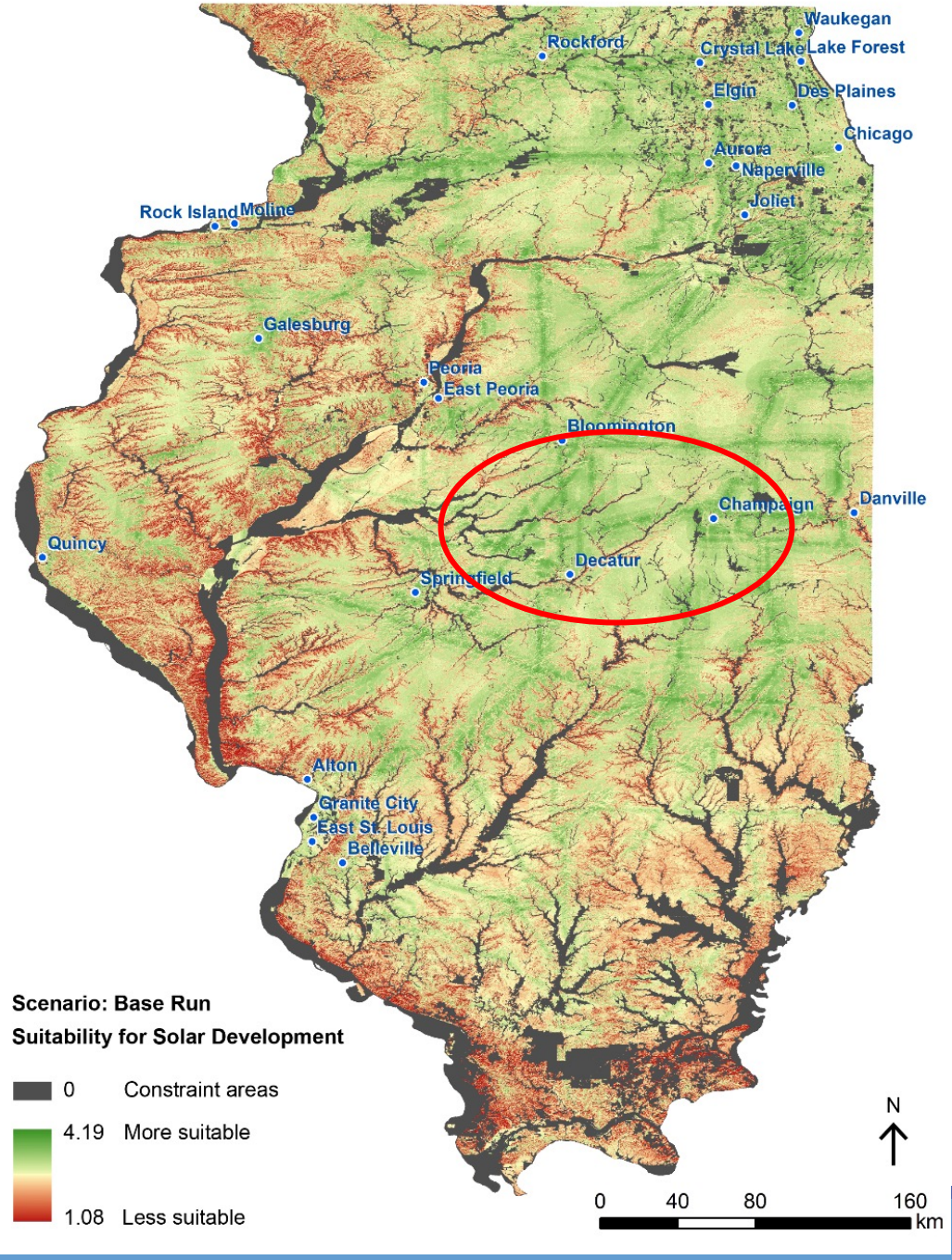
Criteria	Weight				
	Base Run	SA1	SA2	SA3	SA4
Solar Rad. (C1)	0.390	0.364	0.142	0.101	0.111
Slope (C2)	0.169	0.200	0.071	0.057	0.111
Aspect (C3)	0.054	0.137	0.030	0.023	0.111
Elevation (C4)	0.057	0.140	0.031	0.024	0.111
LULC (C5)	0.098	0.046	0.367	0.035	0.111
Pop. Den. (C6)	0.027	0.019	0.256	0.014	0.111
Road Net. (C7)	0.051	0.028	0.028	0.229	0.111
Trans. Lines (C8)	0.136	0.052	0.061	0.341	0.111
Crop Prod. (C9)	0.017	0.014	0.013	0.176	0.111
Sum	1.000	1.000	1.000	1.000	1.000

Results of Solar Development Suitability

Solar Development Suitability in IL

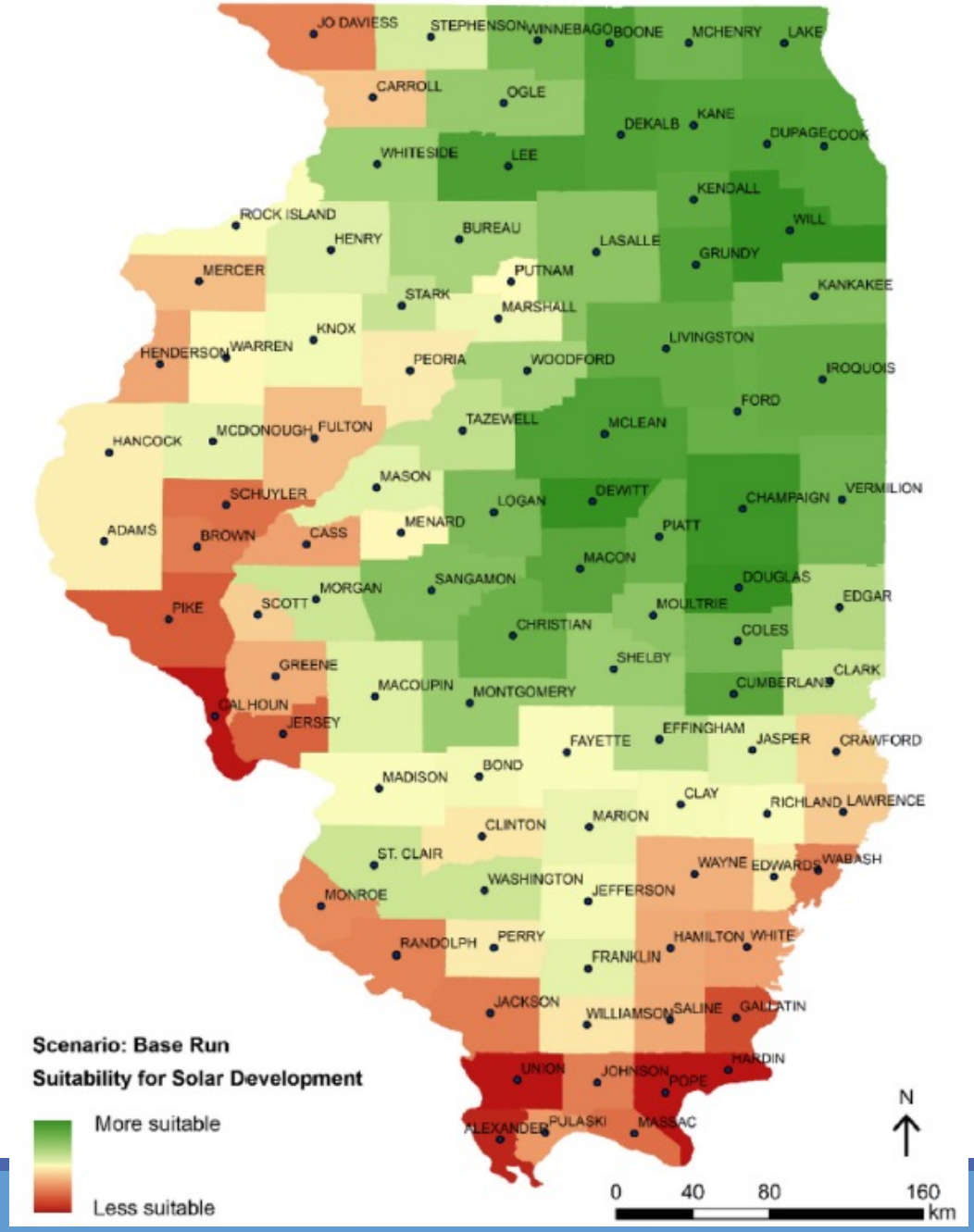
- Weights of Criteria from AHP

Criteria	Weight
Solar radiation (C1)	0.390
Slope percentage (C2)	0.169
Aspect (C3)	0.054
Elevation (C4)	0.057
Land use and land cover (C5)	0.098
Population center density (C6)	0.027
Accessibility to road networks (C7)	0.051
Distance from transmission lines (C8)	0.136
Crop productivity (C9)	0.017
Sum	1.000



Solar Development Suitability in IL

- A visual inspection of the result roughly reveals that the central parts of the state, especially around Decatur, Champaign, and Bloomington, have the highest potential.
- This result corresponds to the real-world undertaking that the UIUC has constructed solar farms in the Champaign area (Solar farm 1.0 and 2.0) and the Champaign County Board recently (January 2019) approved construction of a huge solar farm (1600 acres) on the east of Sidney.
- However, the southern Illinois in which many state parks are located shows low suitability.



Scenario Comparison (Sensitivity Analysis)

	Weight				
Criteria	Base Run	SA1	SA2	SA3	SA4
C1	0.390	0.364	0.142	0.101	0.111
C2	0.169	0.200	0.071	0.057	0.111
C3	0.054	0.137	0.030	0.023	0.111
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C5	0.098	0.046	0.367	0.035	0.111
C6	0.027	0.019	0.256	0.014	0.111
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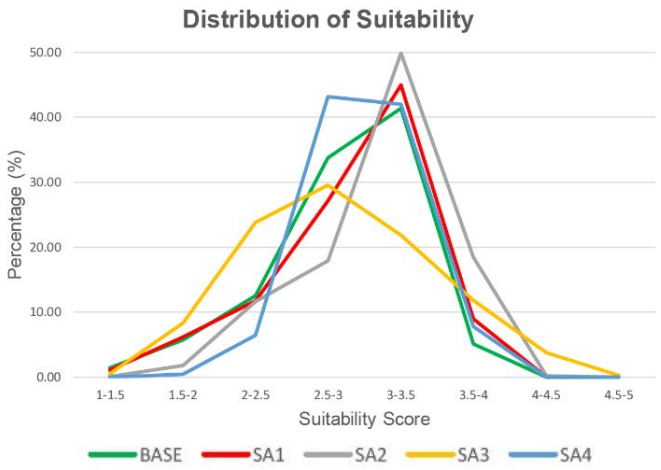
C9	0.017	0.014	0.013	0.176	0.111
Sum	1.000	1.000	1.000	1.000	1.000

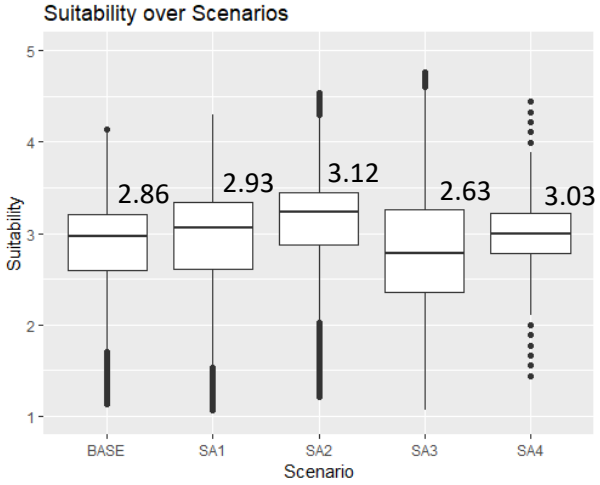
Since criteria and their weight are subject to being replaced with others, sensitivity analysis produces a useful outcome to predict how the result will change under different purposes and to avoid the risk of the development.

- Four additional scenarios were generated. They include a. Environment-focused scenario (SA1), b. Socials/development-focused scenario (SA2), c. Economy-focused scenario (SA3), and d. Scenario with equal weights (SA4).

- Except for SA4, we applied AHP again to determine the new weights giving the highest importance to specific category criteria. For example, in the case of SA1, we considered that the four criteria under the environmental category were ‘extremely more important’ than any other criteria and inputted values of 9 in a pairwise comparison matrix .

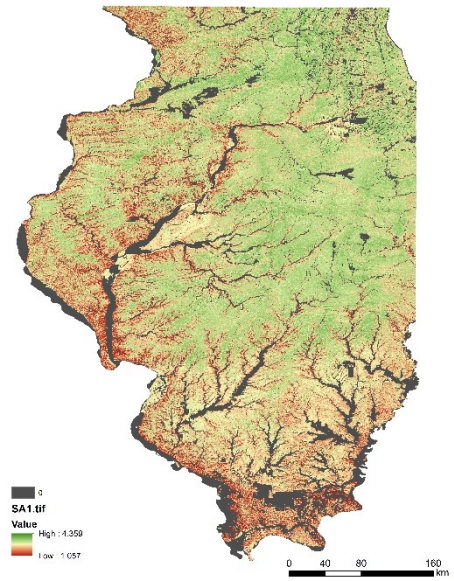
Scenario Comparison (Sensitivity Analysis)



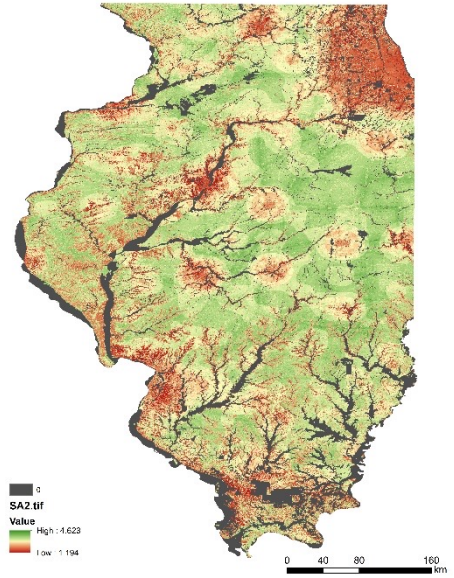


- The suitability for solar development is the most sensitive to the social category (C5 and C6), SA2 shows larger potential areas for the development than any other scenario.

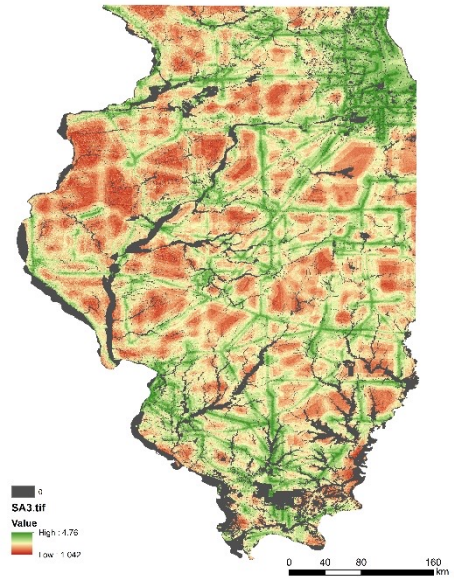
- We predict that for Champaign, the fastest-growing cities in Illinois, if the social criteria are given more weights as the city grows fast, the potential will significantly change.



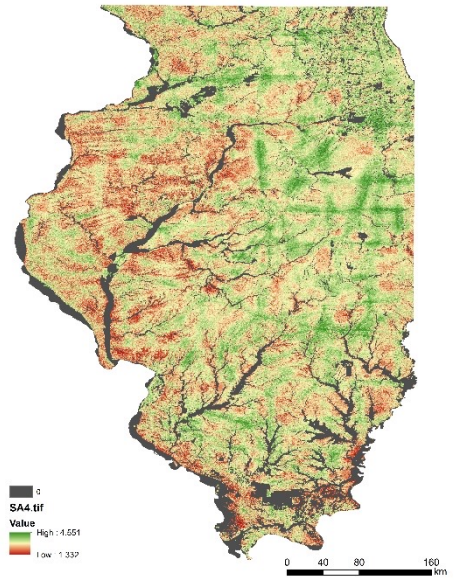
Environment-focused (SA1)



Socials/development-focused (SA2)



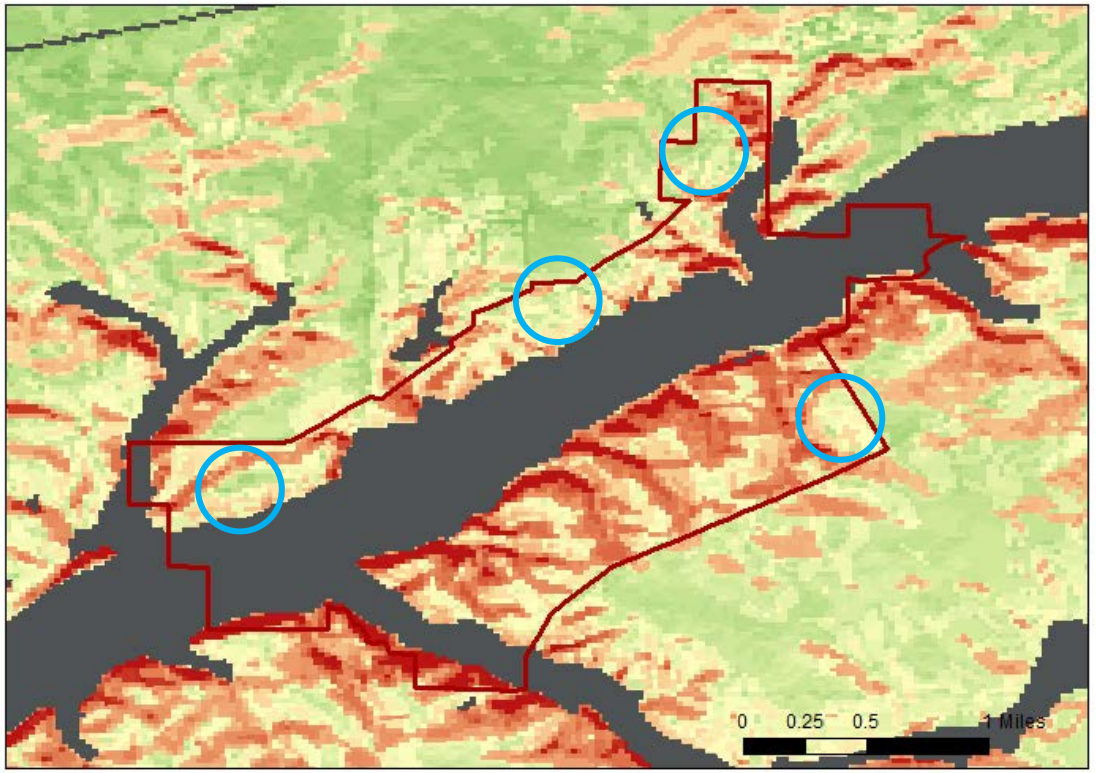
Economy-focused (SA3)

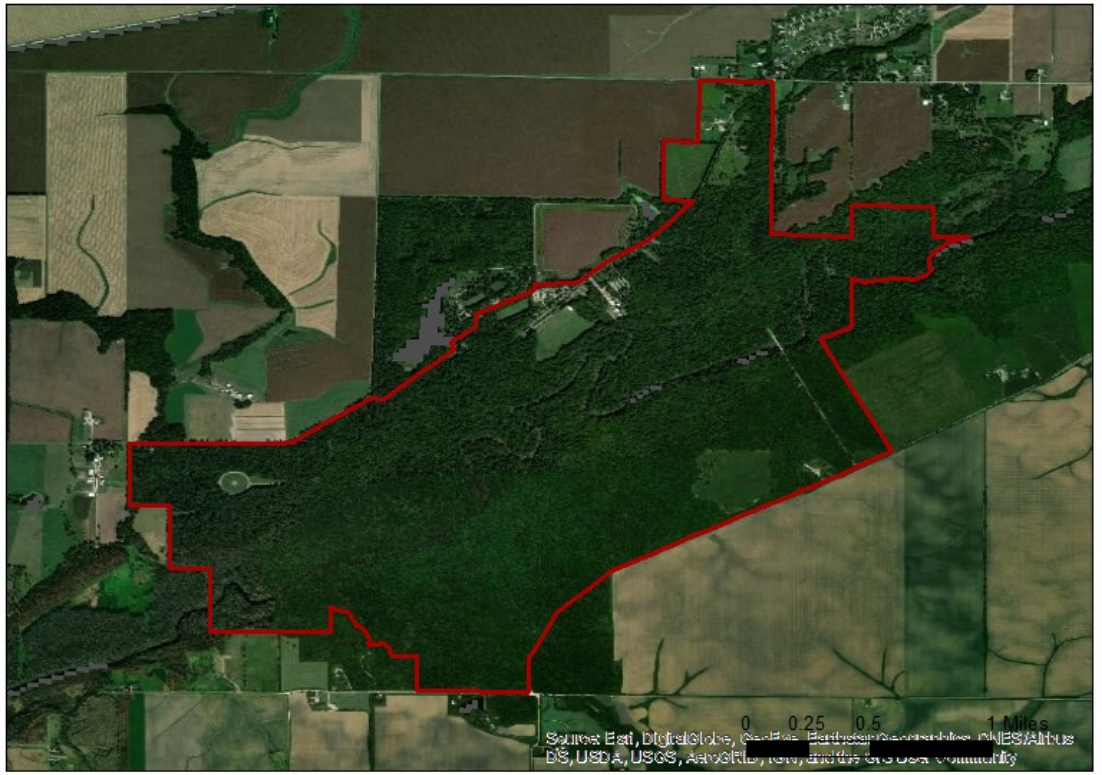


Equally weighted (SA4)

Case Application

Allerton Park





Maximum estimated annual electricity for Sun Singer area statue area:
22579m2 *0.15 *1305.2(kWh/m2/year)*0.86 *0.86 = **3801.6 kWh**

Values of r and PR from NREL

Calculating annual PV solar system output is a function of the equation **E = A * r * H * PR**

- A = Total solar panel Area (m^2)
- r = Solar panel efficiency (%)
- H = Annual average solar radiation on tilted panels (shadings not included)
- PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9)
- E = Energy (kWh)

By NREL